RADC-TDR-62-615

September 30, 1962

STUDY OF FAILURE MECHANISMS IN HIGH POWER RADIO FREQUENCY GENERATING DEVICES

THIRD QUARTERLY REPORT

M. Friedman Axler
R. A. Hein
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General Telephone & Electronics Laboratories Inc.
Bayside Laboratories, Bayside, New York

TR 62-254.3

Contract No. AF 30(602)-2595

Prepared for

Rome Air Development Center
Air Force Systems Command
United States Air Force
Griffiss Air Force Base, New York

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ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
GRIFFISS AIR FORCE BASE
NEW YORK

FOREWORD

This program is supported under contract No.AF 30(602)-2595. The project engineers, and authors of this report are M. Friedman Axler and R. A. Hein. The Scientist-in-Charge of the program is T.G. Polanyi. At Rome Air Development Center, the project engineer is J. Carroll. At the Sylvania Microwave Components Laboratory the program is under the direction of J.S. Needle.

The investigations of tube components and gas-solid interactions are being performed at General Telephone & Electronics Laboratories, Bayside, New York. The gas analyses and electrical testing of operating tubes, and the gas analyses of selected subassemblies, are being carried out at the Microwave Device Operation of Sylvania Electric Products, Mountain View, California.

The gas content analyses of metals presented here and in earlier reports were made by J. Roboz. S. Weisberger performed the spectrochemical analyses.

This is the third quarterly report under the above contract. The contractor's report number is TR62-254.3.

ABSTRACT

The causes of failures in gridded, high-power traveling-wave tubes are being studied through an examination of the gas ambient of operating tubes and of the individual tube components. Omegatron mass spectrometers permanently attached to the unit under test are used for measuring the gas ambient. Electrical parameters of the traveling-wave tube in relation to its gas ambient are discussed. Control data, i.e., the gas ambient produced by the omegatrons processed on two different vacuum systems, are presented. Data on the total gas content of tube materials which can be released upon heating have been determined by a hot-extraction method used in conjunction with a conventional analytical mass spectrometer; such data are reported for stainless-steel and nicoseal tube components. Emission spectrographic analyses for impurities in alundum-coated heater coils are reported.

Title of Report

RADC-TDR-62-615

PUBLICATION REVIEW

This report has been reviewed and is approved.

Approved: DAVID F. BARBER
Chief, Applied Research Laboratory
Directorate of Engineering

Approved: WILLIAM P. BETHKE
Director of Engineering

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION AND SUMMARY

1.1 The objectives of this contract are to determine the origin and effect of gases in traveling wave tubes. This is done principally through the use of omegatron mass spectrometry. For information on the omegatron and its operation, reference is made to the First Quarterly Report, Appendix I.

1.2 The approach which was chosen involves: (1) the analysis of gases in progressively more complex systems -- from materials to fabricated parts to simple assemblies to complex assemblies to finished tubes; (2) the investigation of mechanisms of gas release and absorption; (3) the investigation of electrical characteristics of tubes as they may be affected by specific gases.

1.3 Two complementary methods are used to gain information as to the gas content and its origin in operating tubes -- one is to analyze the gas ambient in tubes operating with an attached omegatron, and the other is to determine from which component in the tube these gases are given off and, if possible, why they are present. To do this, it is necessary to investigate various subassemblies and individual components of the tube under conditions and environments that approximate those existing in the operating tube. The tube part to be analyzed is mounted in a glass envelope to which an omegatron is attached. The unit is then evacuated to very low pressures and heated to selected temperatures for analysis. Since it is necessary to know the contribution of the measuring instrument to the gas ambient, data that can be used as a necessary control are obtained on the gas ambient of an omegatron operated and processed in conjunction with a vacuum envelope representative of the type of system in which investigations on the outgassing of the components are carried out.

1.4 When it is desired to know the total gas content of a tube component, conventional mass spectrometric analyses are made using the hot extraction method. Reference is made to Appendix II of the First Quarterly Report for detailed information on this technique.

1.5 PROJECT STATUS AND SUMMARY

1.5.1 Since many of the investigations must by necessity proceed separately before final synthesis can be attempted, this "Project Status and Summary of Work" has been prepared to give the reader an over-all view of the activities.

A major effort during this reporting period was devoted to measuring the gas ambient and the electrical characteristics of operating traveling wave tubes at various stages of life. Six traveling wave tubes have now reached over 300 hours of life and four more have been started on life. It is expected that interesting correlations between gas and electrical characteristics may soon be forthcoming. It should be noted that the tubes which are being investigated are all of high quality, thus increasing the probability of detecting failure mechanisms relevant to long life problems. Since the mechanics of obtaining good tubes from the production lines, of attaching omegatrons to these tubes, of combining regular production life testing, and quality checks with laboratory measurement is now under control, increasing attention is being directed to search for relevant electrical parameters to be correlated with tube quality and gas content. Attention is now centered on means to evaluate intrinsic cathode quality changes during life which may not be revealed by regular production tests. The life test status of eleven traveling wave tubes is detailed in the report.

Other aspects of the work performed during this period were connected with (1) analyzing the gas evolution of individual tube components, specifically, bare tungsten heaters and attempting to determine the causes of the different gas behavior exhibited by 1-4BE and 1-3DF heaters which were reported earlier; (2) determining the gas ambient created by tube subassemblies and the effect of getters; (3) determining the total gas content of typical materials such as kovar, stainless steel and vacuum melted kovar. The difference between determining total gas content and analyzing the "vacuum ambient" created by an operating part is reviewed in detail in the report. Additional data were obtained on the gas ambient created in time and as a function of different processings by the omegatrons themselves. Such data are needed in order to permit one to differentiate between the gases released by the test part and the background gases. The accumulation of data on gas evolution, although far from complete, permits one already to infer some gas kinetic properties of the finished tubes and to direct attention to additional investigations. A summary of the results obtained on the above topics follows. A detailed description of the experiments and quantitative data is given in the body of the report.

1.5.2 Gas Ambient Produced by Omegatrons

Measurements used as a control were performed on omegatrons processed on two different vacuum stations. For an omegatron with a residual gas pressure of about 1×10^{-7} Torr at tip-off, it is shown that

there is a transient methane partial pressure just after the omegatron beam current is turned on and after it has been operating for about 15 minutes. There is also a slow pumping of nitrogen by the omegatron filament. For an omegatron with a residual gas pressure of $\simeq 10^{-10}$ Torr, the transient methane pressure has not been observed.

1.5.3 Gas Evolution from Operating Tungsten Coils

The gas evolution from operating uncoated tungsten heater coils of the 1-4BE and 1-3DF tube types was analyzed. Both coils behave in a similar manner; mostly N_2 is evolved at elevated temperatures and is not pumped as the heater coils are returned to room temperature. Samples of 1-3DF uncoated tungsten coils were fired in H_2 and NH_3 and then investigated for gas evolution with the omegatron; both evolved N_2, but the H_2 fired coil did not evolve H_2 or CO, whereas the NH_3 fired one did. Emission spectroscopic analyses were made on both the alundum coating and uncoated tungsten wire. The data obtained show that the 1-4BE coating has more impurities than the 1-3DF coating. An evaluation of these tube components, that is, alundum-coated heater coils is still in progress.

1.5.4 Subassemblies

Dispenser cathode assemblies of the 1-3DF type were investigated for gas evolution at different cathode temperatures; mostly N_2, H_2, and CH_4 are evolved but there is an indication that desorption rate and temperature do not exhibit a direct relationship.

Additional electron guns of the 1-4BE type with and without getters have been studied for gas ambient, and the results agree with those presented in the Second Quarterly Report. Large amounts of N_2 were evolved from the guns over a short period of time; afterward, the getter reduces the partial pressures of N_2 and Ar.

1.5.5 Total Gas Content of Materials

The total gas content of many of the tube components has been obtained using a "hot extraction method" in conjunction with a commercial mass spectrometer. All kovar parts of the 1-4BE and 1-3DF tube types were analyzed, as well as all stainless steel parts of the 1-4BE tube.

As a control, several "nicoseal" vacuum melted kovar parts of a production type TWT similar to the ones investigated under this contract have also been investigated. It was found that, in general, parts formed of sheet metal evolve less gas than parts made of tubing. There is not much difference in gas evolution between nicoseal and kovar sheet, but nicoseal tubing evolves less gas than kovar tubing. The gas content of the stainless steel is generally lower than that of kovar except for H. The 1-3DF tube is fabricated with many more stainless steel parts than the 1-4BE, so this may prove to be one of the significant factors in evaluating a source of gas in tubes.

2. WORK PERFORMED DURING QUARTER

2.1 INVESTIGATION OF TRAVELING-WAVE TUBES

Two typical traveling-wave tubes in production at Mountain View have been chosen for this program. One, designated 1-3DF, is a medium-power cw amplifier which operates from 8.0 to 11.0 kMc; the other, designated 1-4BE, is a high-power pulsed amplifier which operates from 2.5 to 4.0 kMc. The electrical test specifications on these tubes are given in Appendix III of the First Quarterly Report, and outline drawings of the 1-3DF and 1-4BE tubes are shown in Figs. 16 and 17 of the same report.

The traveling wave tubes, each with an attached omegatron (constituting a twin-tube), are processed according to Tables V, VI, and VII of the First Quarterly Report.

After processing, the traveling wave tube is electrically tested according to the MIL Spec. The twin-tube is then inserted into the omegatron console and the gases in the tube are periodically measured for the first ten hours. After this, the tube is life tested, as described in Table I of the Second Quarterly Report, for approximately 430 hours (200 hours above the MIL specification).

2.1.1 Traveling Wave Tubes on Test

The life-test status of the traveling-wave tubes being tested for this program is given below:

Tube Type 1-3DF

Tube No. 1. Life test has been completed, and gas and electrical data have been taken (see Second Quarterly Report). The tube is awaiting final engineering evaluation.

Tube No. 4. An additional 240 hours of life were accumulated on this tube since the previous reporting period (see Fig. 5 of the Second Quarterly Report for data on the gas ambient up to 60 hours). Data on gas content and electrical characteristics have been taken for 300 hours, and the life test is continuing.

Tube No. 5. This tube has been operating for 300 hours on life, and the life-test is continuing. Gas data and electrical data are being collected.

Tube No. 6. The sixth tube has been operating for 10 hours and is continuing on life-test. Gas and electrical data are being collected.

Tube No. 7. This new tube is presently on the pumps and, if time permits, will replace tube No. 2, which failed mechanically (see Second Quarterly Report).

Tube Type 1-4BE

Tube No. 1. This tube has completed 450 hours of life (see Second Quarterly Report for data up to 410 hours). All gas data have been taken and are awaiting evaluation.

Tube No. 3. This tube could not be used as a life-test tube because the omegatron failed. The omegatron was tipped-off and the traveling wave tube shipped out as a production tube.

Tube No. 4. All life-test data have been taken and are awaiting evaluation.

Tube No. 5. On life for 382 hours. Gas data and electrical data have been taken.

Tube No. 6. This tube has been processed, tipped-off and will be put on test.

Tube No. 7. This tube has just begun life-test.

2.1.2 Correlation of Electrical Parameters with Gas Ambient

Considerable effort was expended this quarter to determine suitable electrical parameters to correlate with the gas ambient data. All electrical data taken during routine testing of the 1-4BE tube No. 1 were plotted in an attempt to correlate gas ambient and tube life. As shown in Figs. 1 and 2, there appears to be a relationship between a change in the gas ambient and perveance. This correlation, however, has not been observed in the other tubes studied.

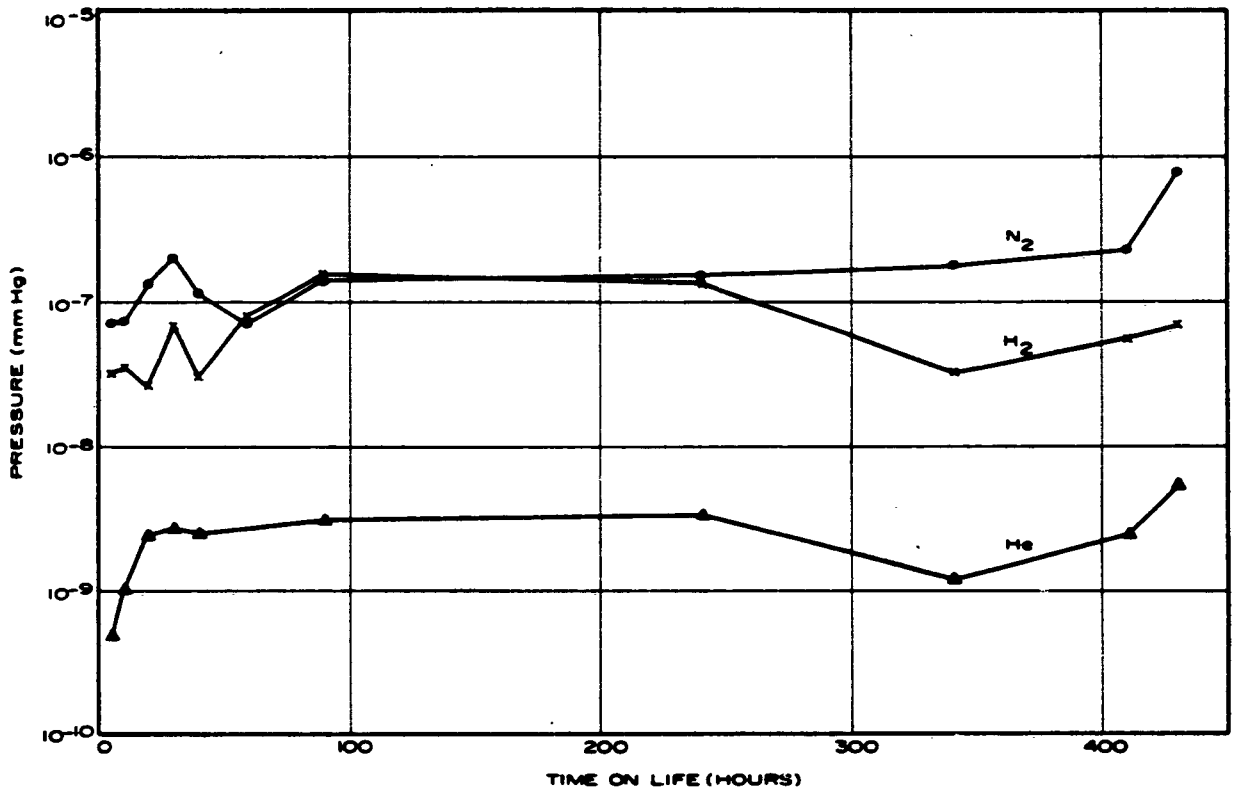

Fig. 1. Gas ambient of life-test tube No. 1, 1-4BE as function of life.

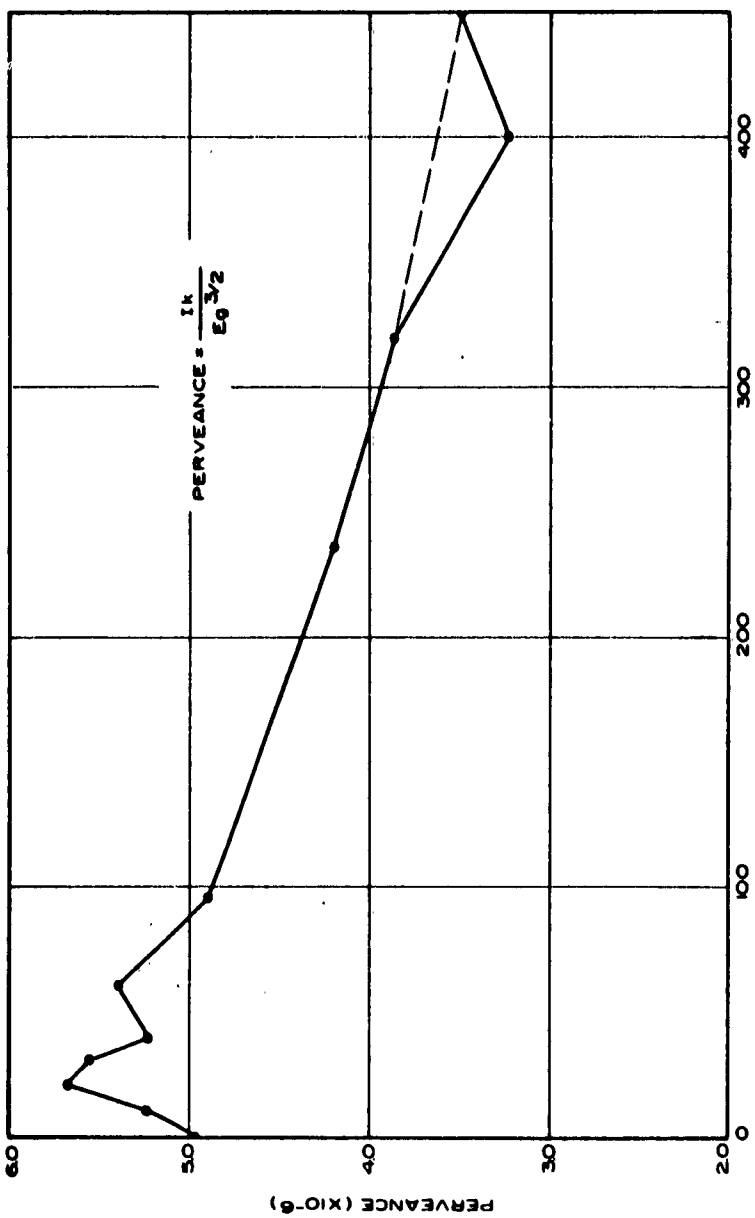

Fig. 2. Perveance of life-test tube No. 1, 1-4BE as function of life.

In addition to the routine electrical measurements, phase-change measurements were completed on a 1-4BE tube. It had been anticipated that phase change of the rf signal through the tube would be a sensitive measure of the electron beam condition, and hence, a sensitive measure of the gas ambient changes. However, it has been shown that the measurements are less sensitive than others being considered.

Another parameter presently being measured is the synchronous helix voltage (phase velocity measurement). The synchronous helix voltage is the helix voltage at which maximum power output is attained. These measurements are in their initial stage and could not yet be evaluated.

A third test being performed is the "Dip Test" following the method of Bodmer.[1] Briefly, the test is conducted as follows: the tube is operated normally. After the tube has reached equilibrium, the heater voltage is turned off for a period of 3 to 10 seconds. The heater voltage is then returned to its specified value after a predetermined time interval. As the cathode cools the cathode current decreases. The amount by which the cathode current is reduced is a sensitive measure of cathode activity. This test is presently being applied to both tube types being studied.

2.2 GAS AMBIENT PRODUCED BY OMEGATRONS

To determine the contribution of the measuring instrument, the omegatron, to the gas ambient, control data are being obtained from tests on omegatrons alone. This information also gives the background (residual gases) in the system.

In addition to the omegatron already tested (see the Second Quarterly Report), two new omegatrons were processed and analyzed for gas ambient and ion pumping.

The first of these omegatrons has been processed on a VacIon pump system and tipped-off at $\sim 10^{-8}$ Torr. The data are presented in Table I. The first two rows give the partial pressures of residual gas four hours after tip-off and again about four hours later; the only significant change is a drop in the methane as expected from earlier experiments performed in these Laboratories; the expected rise in H_2 due to

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1. M.G. Bodmer, IRE Trans. on Electron Devices, 5, 1, 43-44 (1958).

TABLE I

Gas Ambient of Omegatron Sealed-Off VacIon System

Operating time	Partial pressure x 10^{-9} Torr									Remarks
	H_2	H_e	Ar	CO_2	N_e	H_2O	CO	N_2	CH_4	
4 hours after processing	4.4	6.5	30	0	4.3	0.2	3.5	450	51.	Sealed-off ~10^{-8} Torr. Measurements taken at sensitivity of 10^{-11} and 10^{-10} Torr background
4-1/2 hours later	1.8	8.4	37		5.1	0.6	5.0	480	14	
1 day shelf life										
I_b ON	0.6	43	42		0	0	7.5	540	180	Omegatron "cold"
10 min later	0.8	45	42		6.6	0	0	490	3.3	Omegatron "warming"
1/2 hour later	0.5	43	41		8.1	0	0	450	2.1	Omegatron "warm"
3 hours later	0.2	48	42		5.6	0.1	0	216	1.5	
1-1/2 hrs. later	0.2	46	40		5.8	0.1	0	144	1.2	
2-1/2 day shelf life										
I_b ON	0.5	156	44		9.5	0	3.0	250	52	Omegatron "cold"
10 minutes later	0.7	147	42		6.6	0	0	230	1.2	Omegatron "warming"
20 minutes later	0.3	138	40		8.7	0.05	0	195	1.4	Omegatron "warm"
1 hour later	0.2	144	41		6.6	0	0	148	1.2	
5 hours later	0.1	162	45		6.9	0	0	55	0.46	B shut off
18 hours later	0.6	192	42		6.8	0	0	23	0.34	between scans
1/2 hour later	-	195	--		-	0	0	22	0.54	

the dissociation of CH_4 was not observed, but this may be due to the reaction of the hydrogen to form water; a slight rise in the H_2O was observed. The data taken after one day "shelf-life" and again after another 2-1/2 days "shelf-life" are shown in the remaining rows in Table I. Data taken as soon as the beam current of the omegatron is switched on are called omegatron-"cold" data, and that taken after operating the omegatron for 20 minutes are called omegatron-"warm" data. The only significant transient condition between these two sets of data is a relatively large drop in the methane pressure which occurs after operating the omegatron for ten minutes (a warming omegatron). The nitrogen pressure also decreases, but to a smaller extent. With continued operation of the omegatron the methane continues to decrease at a very slow rate; i.e., at 0.2×10^{-9} Torr/hour (or 0.33×10^{-11} Torr/minute). After 24 hours of operation, the methane pressure essentially levels off. Whether the initial ("cold" data) measurement of the methane pressure is the true residual partial pressure of methane in the gas ambient of the omegatron or whether turning on the omegatron causes a methane burst cannot be determined from these data. The rate of decrease in the nitrogen pressure, as shown in Table I, is continuous, but not constant.

All data on tube components are taken with a "warm" omegatron since such operation provides a steady-state condition except for the slow pumping of nitrogen. The gas ambient of the operating omegatron and the nonoperating tube part is considered as background or control data, and changes in the partial pressures of the gas ambient can be normalized to it.

The gas ambient of the second omegatron processed on an ultra-high-vacuum system was also obtained. In this experiment, a degassed and nonoperating Bayard-Alpert gauge is in the system. The omegatron and gauge are closed off from the pump by a Granville-Philips high-vacuum valve. Immediately after closing the valve, the only measurable gas was helium (at a sensitivity of 1×10^{-11} Torr). The omegatron beam current was then shut off. Two hours later, the current was turned on and gas spectra obtained as shown in the first column of Table II; the second column in the table gives the gas spectra taken twenty-five minutes later. On turning on the omegatron, there was a small burst of argon which immediately disappeared. Experiments in progress at present indicate this effect may be due to sorption effects at the surfaces of the nonoperating ionization gauge. The only other significant gases present are nitrogen and methane of equal, but very small, partial pressures. With the omegatron operating for twenty-five minutes, the nitrogen disappeared, but the methane remained about the same.

TABLE II

Gas Ambient of Omegatron on Ultra-High-Vacuum System

Gas	Partial pressure x 10^{-11} (Torr)	
	Omegatron "cold"	Omegatron "warm" (for 25 minutes)
H_2	0	0
H_e	410	---
Ar	300/0.0	(Trace)
CO_2	0	0
Ne	0	0
H_2O	0	0
CO	0	0
N_2	10.0	0
CH_4	10.0	13.0

Remarks

1. Immediately after closed-off from pump, only gas measurable is He, partial pressure = 49.5 x 10^{-11} Torr.
2. "Cold" data taken on 5 minute drive, except H_2 on 15 minute drive. "Warm" data taken on 15 minute drive.
3. Slant bar indicates short lapse of time.
4. Pressure reading of 0 x 10^{-11} Torr means gas not observed at limit of sensitivity of instrument.

Thus, the "transient" methane property is not observed at ultra-low pressures. This does not mean that it may not exist. Further experiments will be undertaken to determine if there is a very rapid change (within less than a minute) in the methane pressure or if the methane pressure decays at a very slow rate. In any case, the present data do not show any transient effect of the operating omegatron on the residual gas in a high-vacuum environment.

2.3 GAS EVOLUTION FROM ELECTRON TUBE COMPONENTS

All of the components comprising the traveling-wave tubes have been catalogued together with the pertinent processing schedules used at Mountain View. The components chosen for investigation at the Research Laboratories are samples from production runs of the tubes at Mountain View.

2.3.1 Heater Coils

Data on the gas ambient contributed by coated heater filaments from both tubes were presented in the Second Quarterly Report. In summary, it was found that both filaments evolve a considerable amount of N_2 when raised to operating temperatures; the 1-4BE heater subsequently pumps the N_2 when the temperature is decreased by turning off the filament voltage, but the 1-3DF heater does not exhibit this pumping action.

To determine the nature of this phenomenon the following investigations were performed: (1) Uncoated heaters of each type were examined for gas evolution when subjected to processing temperatures; (2) uncoated heaters of one type (1-3DF) were processed in the two atmospheres which are used in processing the coated heaters,* and (3) a spectrochemical analysis was performed to determine impurities in heater coatings and tungsten wire. Differences were found in the outgassing characteristics of the heater wires that were differently processed, but not between different types of tungsten. Differences were also found on the impurity contents of the two types of heaters. So far, however, no certain cause has been determined for the different behavior of the two types of filaments in regard to their ability to pump nitrogen. Details of these investigations are given below in 2.3.1.1 and 2.3.1.2.

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* The 1-3DF heaters are processed in dissociated NH_3; the 1-4BE heaters in wet H_2.

2.3.1.1 Gas Evolution from Uncoated Tungsten Heaters

Uncoated tungsten heater coils of each type were separately examined on the high vacuum system. The 1-4BE coil is "non sag" black tungsten wire, 125 mg/200 mm, cleaned and annealed in hydrogen; the 1-3DF coil is also a non-sag tungsten wire, 70 mg/200 mm, chemically cleaned in a sodium hydroxide solution and then partially annealed in a reducing atmosphere. It has a higher tensile strength than the 1-4BE wire but is not straight. These uncoated heater coils had not been subjected to the firing process that is used in coating them, but each uncoated heater coil was subjected to the same processing schedule (voltage, current, and time parameters) used in traveling wave tubes.

After processing, the uncoated heater coil was sealed-off from the pumps and then temperature-cycled by raising the filament voltage to 6.3 volts. The chief gas evolved from both heaters was N_2. Upon returning the voltage to zero, the N_2 partial pressure remained about the same for both heaters. Therefore, the uncoated 1-4BE heater does not pump N_2 as the coated heater does.

2.3.1.2 Effect of Firing Atmosphere on Gas Content of Uncoated Heater Coils

Five 1-3DF uncoated heaters were fired: two in dry hydrogen and three in dissociated ammonia for 10 minutes at 1550°C. The heaters were then enclosed in separate glass envelopes provided with omegatrons, evacuated, and maintained at 1500°C for 30 minutes on the processing pumps.

The gas ambient of each envelope with the heater coil at normal heater power input was analyzed. A comparison of the gas ambients of the heaters fired in dry hydrogen with those fired in dissociated ammonia is shown in Fig. 3. The diagram gives average values; the reproducibility from sample to sample was excellent. The significant result of firing in the H_2 atmosphere is that the heater coil subsequently produces no evolution of CO or H_2, whereas firing in the NH_3 atmosphere subsequently produces evolution of these gases; the difference in N_2 evolution is not very significant.

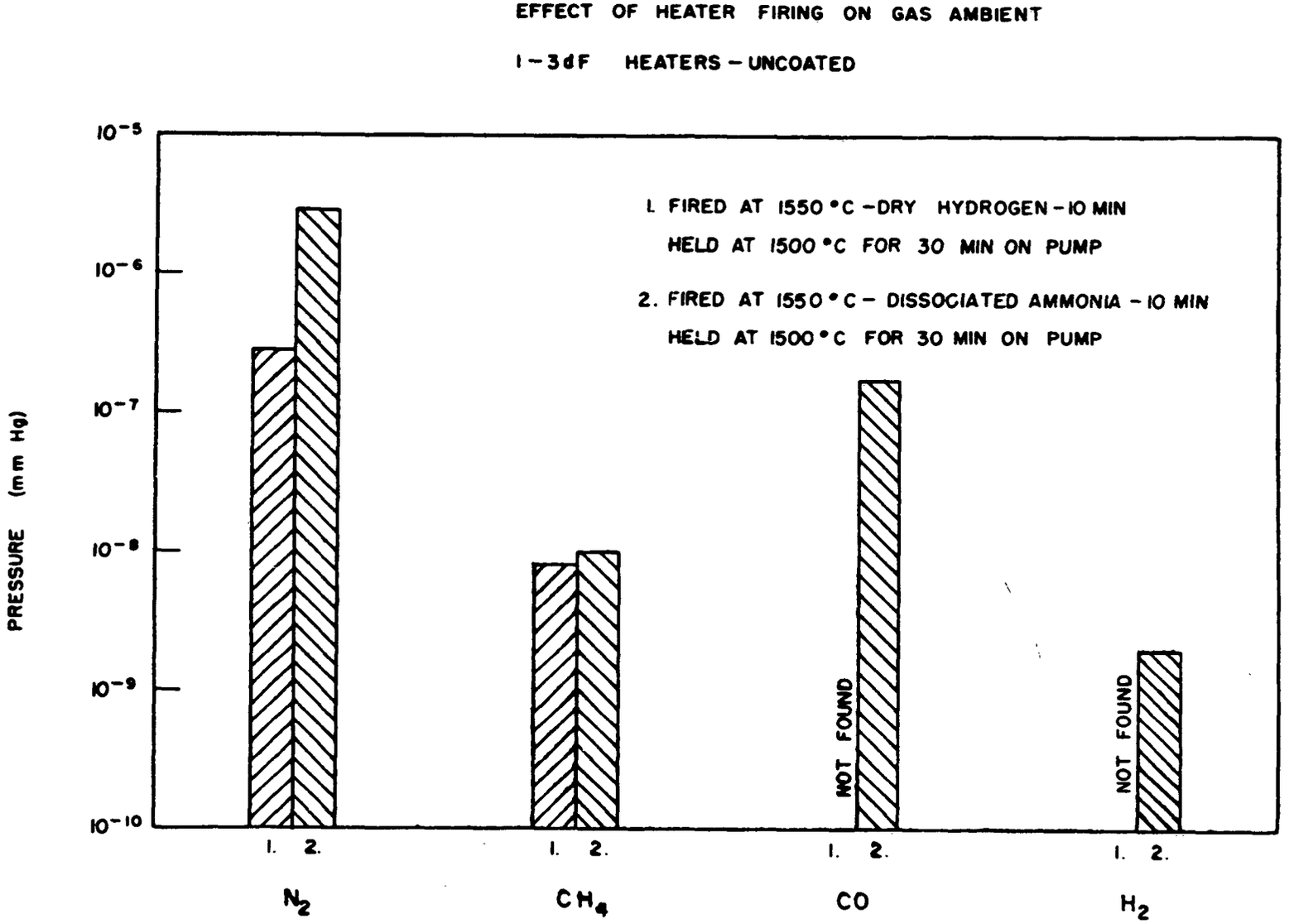

Fig. 3. Effect of heater firing on gas ambient of 1-3DF uncoated heater coils.

2.3.1.3 Spectrochemical Analyses of Alundum Coating and Heater Wire

Emission spectrographic analyses for impurity contents of the heater coating are shown in Table III. There are marked differences between the Mg and Si content of the 1-4BE and the 1-3DF coatings: the Si and Mg contents of the 1-4BE are respectively ten times and fifty times greater than those in the 1-3DF coating.

The Mg impurity probably originates in the cataphoretic bath used for coating the 1-4BE heater, since it contains magnesium nitrate. Since no binder is used in cataphoretically coating the 1-4BE heater, the Si is probably a contamination in the tungsten. This is borne out by spectrochemical analysis of uncoated tungsten wire shown in Table IV.

The possible contribution of Mg and Si compounds to pumping of N_2 by the heater is not known at the present time. Information will be sought from pertinent literature or from further experiments.

2.4 GAS EVOLUTION FROM AN ASSEMBLED DISPENSER CATHODE

The electron source in the 1-3DF traveling wave tube is a dispenser cathode. Therefore, an investigation was made to determine the gas ambient arising from a dispenser cathode assembly consisting of an impregnated tungsten button, a molybdenum sleeve, a tantalum heat shield, and an alundum-coated tungsten filament heater; the size and configuration of the assembly is approximately equal to the 1-3DF cathode assembly. No getter is used in the glass vacuum envelope.

Gas evolution data were taken with the omegatron at cathode temperatures of 1050, 1100 and 1150°C on two similar cathode assemblies (designated No. 1-A and 2-A). Normal operating temperature is 1050°C. Figure 4 shows the change of nitrogen partial pressure in two similar assemblies at three different temperatures. The increased partial pressure of nitrogen at elevated temperatures is probably due to diffusion from the bulk of the material. Number 1-A exhibited a higher increase in nitrogen than did No. 2-A; however, the general characteristics were similar. Figure 5 shows the change of partial pressures of hydrogen at the three temperatures. In assembly 2-A the hydrogen pressure increased slightly with temperature, while in assembly 1-A it decreased slightly. One could explain such different behavior by assuming that gas evolution and pumping mechanisms exist and postulating that slight changes in the condition of the experiment shift the net result in one direction or the other.

TABLE III

Major Impurities in alundum (Al_2O_3) Coating

Tube	Impurities (ppm)				
	Fe (Avg.)	Mg (Avg.)	Si (Avg.)	Cr	Ti
1-4BE	338	4,450	2210	trace	trace
1-3DF	23	90	224	trace	trace

TABLE IV

Impurities in Tungsten Heater Wire

Tube	Average impurities (ppm)		
	Fe	Si	Al
1-4BE	64	101	25
1-3DF	33	40	faint trace

There are also faint traces of Mg and Cn present in both heater wires.

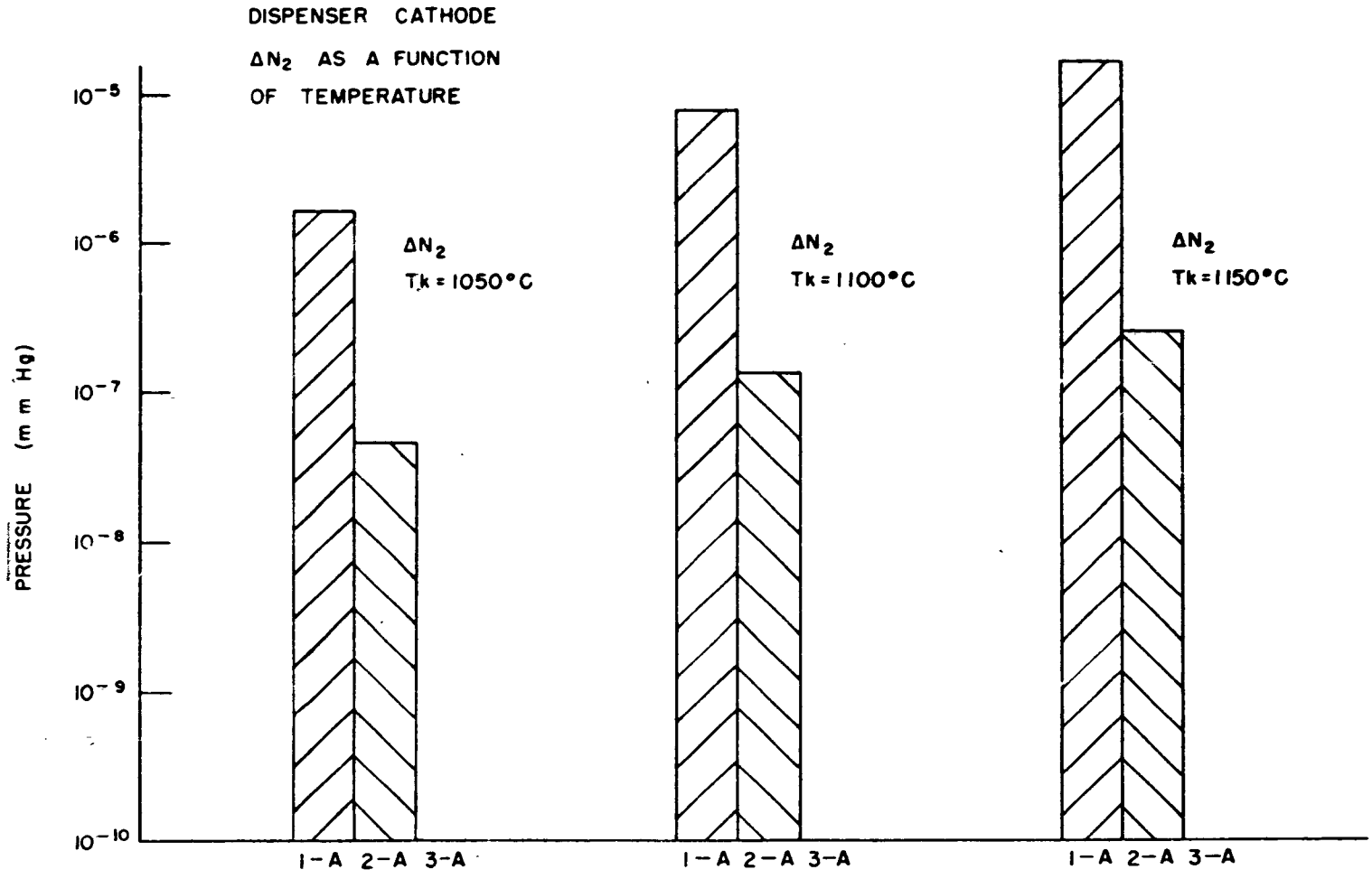

Fig. 4. Change of N_2 pressure evolved from two dispenser cathode assemblies as function of temperature.

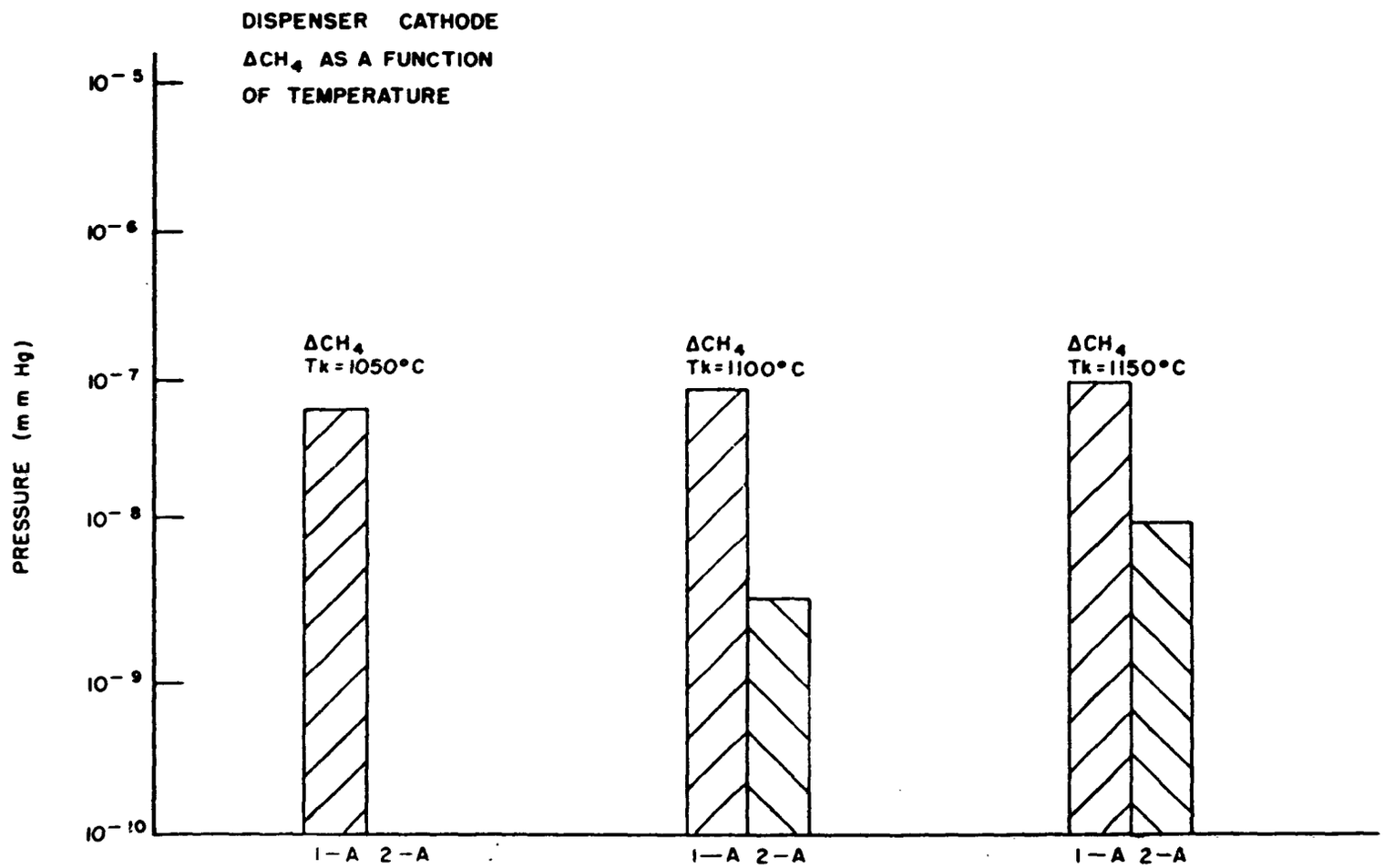

Fig. 5. Change of H_2 pressure evolved from two dispenser cathode assemblies as function of temperature.

The evolution of methane from the dispenser cathode assemblies as a function of temperature is shown in Fig. 6. As with nitrogen, a generally increasing evolution (or formation) of methane with higher temperature was observed. The higher ΔCH_4 level in No. 1-A could be the result of a slightly higher carbon content in the metal parts. Carbon monoxide was not observed during this test. The limit of sensitivity for CO is approximately 3×10^{-9} Torr, so that CO, if present, is below this level. C_2 and C_3 hydrocarbons were observed during the test of No. 1-A, which perhaps substantiates the presence of higher carbon content in the metal parts of No. 1-A. Evolution of water was observed only in No. 1-A as the cathode temperature increased.

The assembly under test has been represented so far as a simple system in which an increase in temperature caused an increase or decrease in gas partial pressures. The data plotted in Fig. 7 indicate that desorption rate and temperature do not exhibit a direct relationship. There is a general pumping action as the heater voltage is increased from one to three volts. As heater voltage is further increased, there is a rise in all gas partial pressures. Hydrogen was observed to be pumped between nine and fifteen volts. The complexity of the phenomena taking place in this system emphasize the need for a thorough investigation of the gas behavior of isolated tube components.

2.5 GAS AMBIENT OF GETTERS AND GUN TESTER

Five electron gun assemblies were investigated: two electron guns (1-4BE) were provided with SAES (Zr-Al-Th) getters, two with zirconium paint getters, and one with an uncoated cathode coating. Figures 12 and 13 in the Second Quarterly Report represent the gas ambient remaining over the two types of getter-gun tester combinations. This work has been validated by a second test of each getter-gun tester combination. The gases evolved from a 1-4BE electron gun with no getter are shown in Fig. 8 of this report. The large amounts of nitrogen evolved over a short period of time represent a significant contribution to the gas ambient of a tube. Comparison of Fig. 8 with Figs. 12 and 13 of the Second Quarterly Report will demonstrate the effectiveness of the getters in reducing the partial pressures of N_2 and Ar.

2.6 TUBE PARTS

Investigations have commenced on grids of both tube types and on a tungsten spring, used in the 1-4BE helix assembly, mounted on the ultra-high-vacuum manifold shown in Fig. 9. An analysis and evaluation of data taken is in progress.

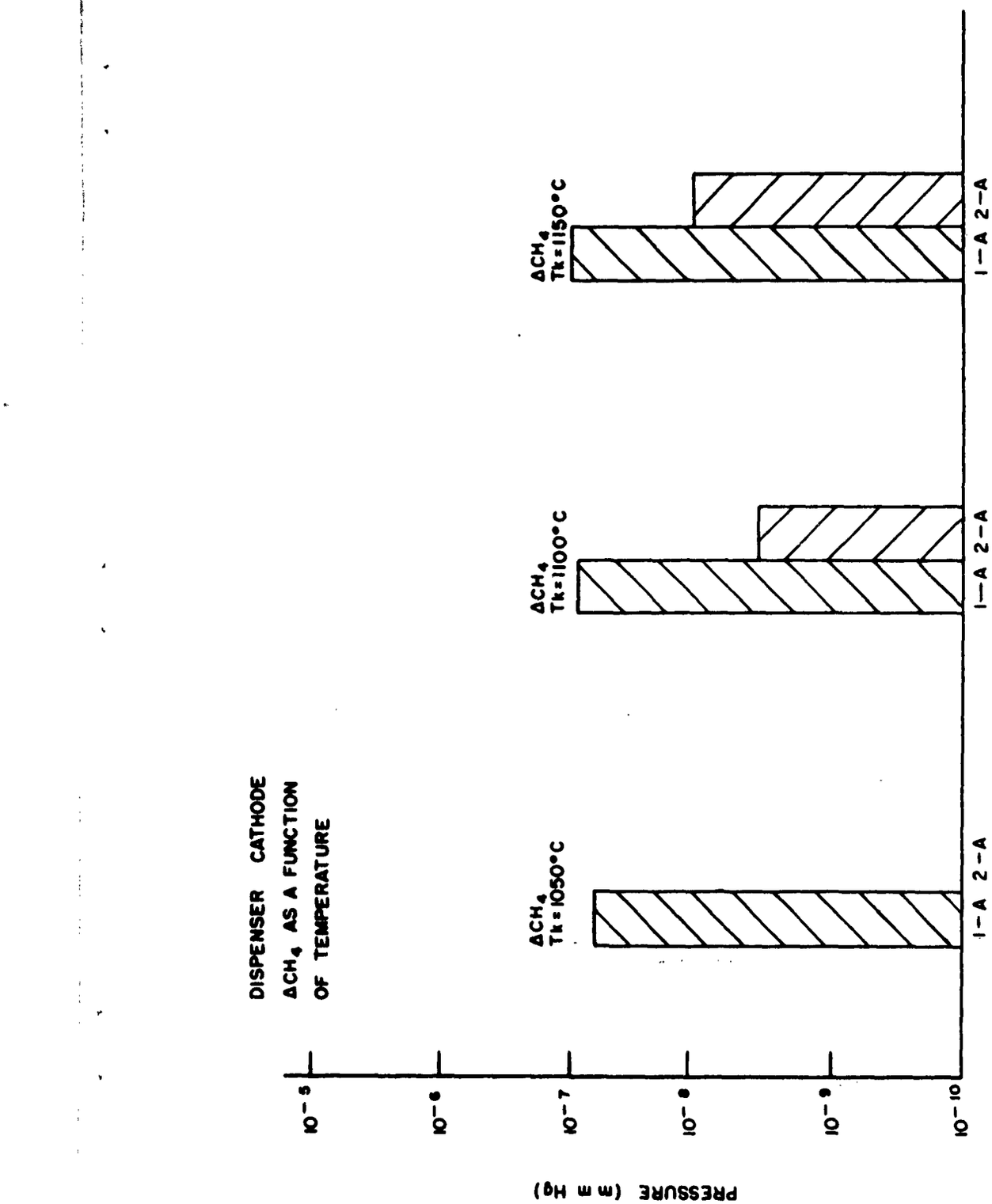

Fig. 6. Change of CH_4 pressure evolved from two dispenser cathode assemblies as function of temperature.

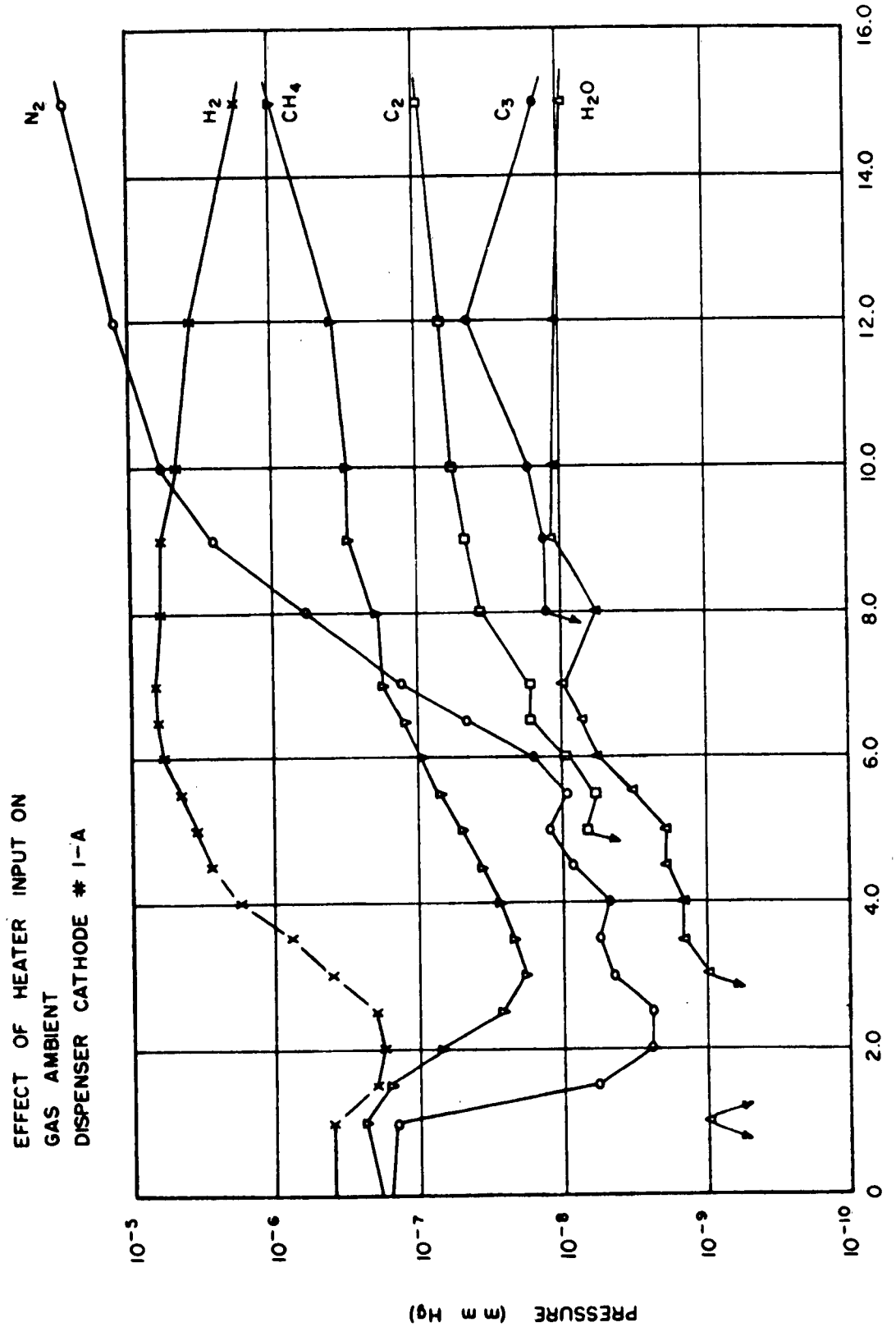

Fig. 7. Effect of heater input on gas ambient of dispenser cathode.

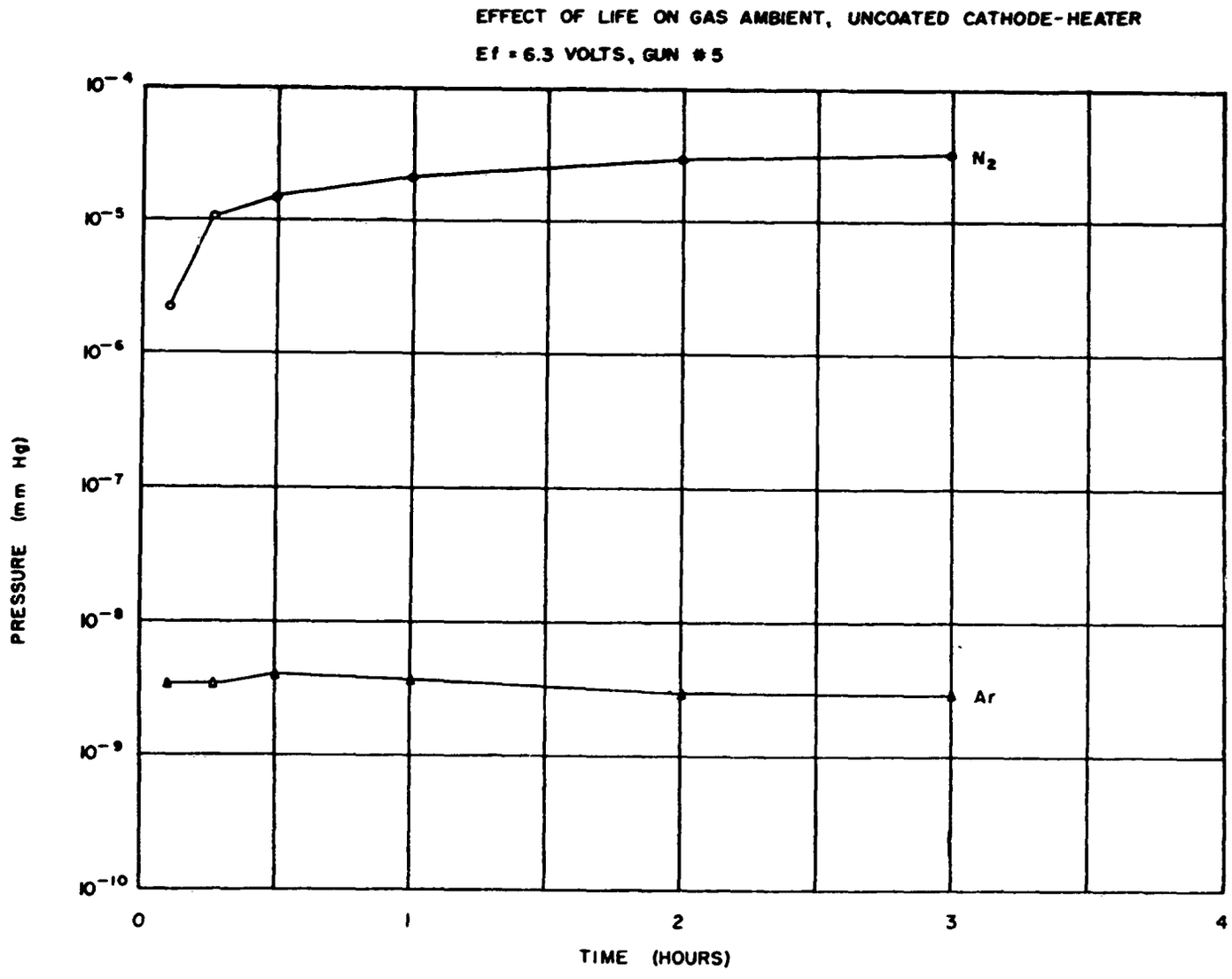

Fig. 8. Effect of life on gas ambient of uncoated cathode - heater assembly.

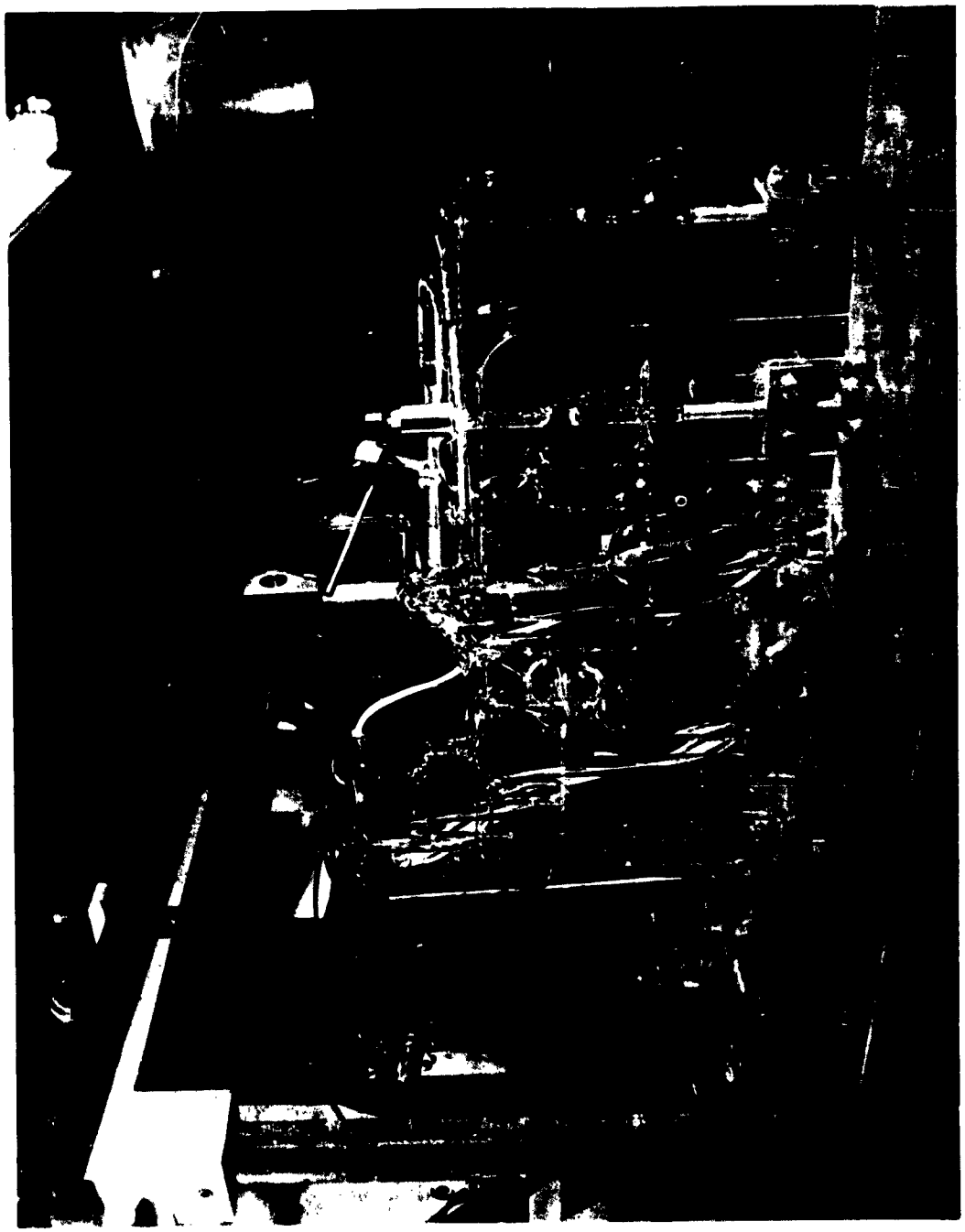

Fig. 9. Photograph of omegatron high vacuum system with assorted traveling wave tube components.

2.7 TOTAL GAS CONTENT OF PARTS

All materials contain gas. The release of this gas is a function of many parameters such as the amount of gas contained, form in which the gas is bound in the solid, and time, temperature, surface properties of the solid, etc. In the manufacture of vacuum tubes one chooses materials which from the very start have a "low" gas content. The mount of gas which can be considered as "low" for a given part has been determined mostly from experience. Subsequent processing further reduces the gas content of the parts. The processing of a part depends on its function in the vacuum tube; e.g. a part that is always cold during operation requires less stringent processing than a part which is operated at high temperatures. The knowledge of the total gas content of a material is important to permit one to determine whether a material is desirable for a given application and, if so, what further processing it requires. It is difficult to determine the total gas content of a material. At times it is not necessary to do so. Glass is an important example; numerous studies have shown that although outgassing from glass never ceases, a knowledge of the time-temperature dependence of the outgassing permits one to process glass in such a way that satisfactory vacuum tubes with glass envelopes can be built for a set of operating conditions. In the case of metals it is also difficult to determine the total gas content; we have shown in our Laboratory that it is practically impossible to release all hydrogen from nickel. Nevertheless, when one heats a metal close to the melting point in a good vacuum, at least 90% or more of the gas content of the metal is released in a period of time of approximately half an hour. This method of determining gas content is referred to as "hot extraction" and was described in detail in the First Quarterly Report, Appendix II. It may be useful to point out here the difference between measuring "total" gas and "gas ambient." Total gas in a good metal is of the order of 10^{-3} Torr-liter per gram of material. If such a quantity of gas were released in a tube of 100 cc volume, it would give rise to a pressure of 10^{-2} Torr. In "gas ambient" studies one is interested in pressures of the order of 10^{-6} to 10^{-7} Torr, i.e., from four to seven orders of magnitude lower. Another consideration may further clarify the difference between these measurements. The limit of sensitivity of the best hot-extraction technique is approximately 10^{-5} Torr-liter per gram. The pressure produced by such an amount of gas in a 100 cc vessel is three orders of magnitude above the maximum pressure at which the omegatron mass spectrometer can operate and about two orders of magnitude higher than the pressure at which any vacuum tube can operate. Determination of total gas content of parts used in traveling wave tubes is reported below.

2.7.1 Kovar Parts

All but one of the kovar parts used in both types of traveling wave tubes were analyzed for total gas content and the results reported in the First and Second Quarterly Reports. The remaining 1-4BE kovar part, the beam electrode, has been analyzed during this reporting period. The beam electrode is formed from kovar sheet. The processing procedure used at Mountain View is as follows: degrease in hot 50% HCl, rinse, dry. Gas evolution data for this part are given in Table V.

Peaks not reported in the table were also found at m/e = 27, 26, 39, 41 and 43 and indicate the presence of C_2 and C_3 hydrocarbons, the estimated quantity for the sum of all hydrocarbons is $2\mu l/g$. It is to be noted that the pressure unit generally used is Torr, but in the data presented here, the unit micron ($1\mu = 1 \times 10^{-3}$ Torr) is used in the conventional manner.

Comparison of Table V with Table XIV in Second Quarterly Report and Table XIII in First Quarterly Report show the same correlation between gas evolution, processing procedure, and material form, i.e., there is no correlation between gas evolution and processing procedure, but there is a correlation between gas evolution and material form. The kovar sheet parts evolve the least amount of gas. The conclusion drawn in previous reports is herein substantiated; i.e., there is a chemical or structural difference between the different forms of kovar so that the gas content differs between them. There is no significant difference observed between the 1-4BE and 1-3DF kovar parts. There are, however, many more kovar parts in the 1-4BE than in the other traveling wave tube and the accumulated effect may be important.

2.7.2 Vacuum Melted Kovar: Nicoseal

Nicoseal is a vacuum-melted type of kovar; it is used in Mountain View in traveling wave tubes similar to the 1-4BE.

Several nicoseal parts were analyzed and compared with the less costly kovar alloy; results are given in Table VI. Nicoseal and kovar sheet parts evolve about the same amount of gas as, for example, is shown for the heat shield in Table VII. However, a nicoseal part formed from tubing, e.g., the cathode support sleeve, evolves considerably less gas than the corresponding kovar part, (see Table VIII).

TABLE V

Gas Content of 1-4BE Beam Electrode: Kovar

Temperature*	H_2 (μl/g)	H_2 (ppm)	CH (μl/g)	H_2O (μl/g)	$CO+N_2$** (μl/g)	CO_2 (μl/g)	O_2 from CO + CO_2 (ppm)
600°C	1.3	0.1	0.4	0.8	3.9	2.0	6.8
1000°C	3.7	0.4	0.4	-	4.2	0.8	5.0

* Two gas extractions are made; one at 600°C and one at 1000°C. Extraction duration is 20 minutes for each.

** The N_2 content is estimated to be less than 10% at 600°C and zero at 1000°C.

TABLE VI

Gas Evolution of Nicoseal Parts*

Component	H_2				CH_4		H_2O		$CO+N_2$	$CO+N_2$	CO_2	O_2 from CO+ CO_2 -	CO_2	O_2 from CO+ CO_2 -	Material form
	600°C µl/g	600°C ppm	1000°C µl/g	1000°C ppm	600°C µl/g	1000°C µl/g	600°C µl/g	1000°C µl/g	600°C µl/g	1000°C µl/g	600°C µl/g	600°C ppm	1000°C µl/g	1000°C ppm	
Cathode support sleeve	3.2	0.4	3.7	0.4	0.3	0.8	0.6	0.3	3.5	11.6	2.7	7.6	1.2	12.1	Tubing
Heat shield	1.0	0.1	3.9	0.4	0.1	1.2	0.3	0.5	1.9	9.9	1.0	3.3	1.8	11.6	Sheet
Focus shield	1.8	0.2	4.1	0.5	0.3	1.1	0.6	0.5	2.9	18.0	1.6	5.3	1.3	17.7	Sheet
Anode	2.8	0.3	2.7	0.3	0.2	0.7	0.1	0.5	1.1	3.7	0.7	1.1	0.7	4.4	Sheet
Beam electrode	1.3	0.1	3.4	0.4	-	0.7	0.1	0.4	1.6	8.8	0.5	2.3	1.1	9.0	Sheet
Grid support sleeve	1.8	0.2	3.6	0.4	0.1	1.0	0.1	0.1	2.4	10.0	0.8	3.5	1.9	11.9	Sheet

* - 20 minute collection

TABLE VII

Partial Gas Content of the "Heat Shield"

Metal	H_2 - 1000°C (µl/g)	CH_4 - 1000°C (µl/g)	O_2 from CO_2 - 1000°C (ppm)	O_2 from CO - 1000°C (ppm)
Kovar*	2.9	0.4	2.6	5.1
Nicoseal	3.7	0.5	8.5	3.1

* Data taken from First Quarterly Report, Table XIII, p. 63.

TABLE VIII

Partial Gas Content of the "Cathode Support Sleeve"

Metal	H_2 - 1000°C (µl/g)	CH_4 - 1000°C (µl/g)	O_2 from CO_2 - 1000°C (ppm)	O_2 from CO - 1000°C (ppm)
Kovar*	5.4	2.3	8.1	26.9
Nicoseal	3.7	0.8	2.1	10.0

* Data taken from First Quarterly Report, Table XIII, p. 63.

More nicoseal tubing parts must be analyzed before a definitive conclusion can be made; however, present results indicate that the tube parts fabricated from kovar sheet contribute as low amounts of gases as can be expected from present metallurgical technology, whereas tube parts formed from kovar tubing contribute larger amounts of gases. A full evaluation of this effect on traveling-wave tube operation can only be made after all parts and materials have been investigated.

2.7.3 Stainless-Steel Components

All internal stainless-steel components of the 1-4BE traveling wave tube have been analyzed for gas evolution. The parts and their processing are listed in Table IX. Gas evolution data are presented in Table X.

As observed previously with regard to the kovar parts, gas evolution is dependent on the material form; the pole piece support which is formed from stainless-steel sheet evolves the least amount of H_2 at 600°C and 1000°C and the least amount of O_2 from CO at 1000°C. The helix connector, formed from stainless-steel rod, evolves the most gas on the average. The other tube parts listed are formed from stainless-steel tubing, and the gas content is similar except for an important difference between the helix barrel and the slotted helix barrel. These two parts are fabricated from the same material in the same way, but the slotted helix barrel undergoes an additional machining and H_2 firing step, as seen in Table IX. From a comparison of the gas evolution data in Table X, it appears that the H_2 firing process lowers the CH_4 and H_2O content and to a lesser degree, the H_2 and O_2 (from CO_2) content. In this instance, in which two similar tube parts are processed differently, a correlation can be made between processing procedure and gas evolution.

2.7.4 Discussion of Gas Evolution Data

Reference is made to the following data: gas content of kovar in 1-4BE, First Quarterly Report, Table XIII; Gas Content of kovar in 1-4BE and 1-3DF, Second Quarterly Report, Table XIV; and Tables V and X above.

TABLE IX

Stainless Steel Parts of 1-4BE

Component	Processing	Material form
Pole piece support	Degrease - clean in HNO_3 + HF rinse, dry	Sheet
Helix barrel	- same -	Tubing
Input end ring	Same as above + H_2 - fire (dry H_2 - 1000°C 10-30 min.) + Vac - fire - 1000°C until outgassed)	Tubing
Helix connector	Degrease - clean in HNO_3 + HF rinse, dry	Rod
Slotted helix barrel	Same as above + H_2 fire (dry H_2, 1000°C, 10-45 min.) on a sizing fixture	Tubing
End ring	Degrease - clean in a HNO_3 + HF rinse, dry, and H_2-fire (dry H_2 - 1000°C - 10-30 min.)	Tubing

TABLE X

Gas Content of Stainless Steel Parts 1-4BE*

Component	H_2				CH_4		H_2O		$CO+N_2$	$CO+N_2$	CO_2	O_2 from CO+ CO_2 -	CO_2	O_2 from CO+ CO_2 -
	600°C µl/g	600°C ppm	1000°C µl/g	1000°C ppm	600°C µl/g	1000°C µl/g	600°C µl/g	1000°C µl/g	600°C µl/g	1000°C µl/g	600°C µl/g	600°C ppm	1000°C µl/g	1000°C ppm
Pole piece support	7.5	0.8	13.6	1.5	0.1	0.2	0.8	1.1	0.5	5.3	0.4	1.1	0.7	5.8
Helix barrel	34.3	3.8	41.7	4.6	0.1	0.4	-	3.3	0.8	10.3	0.3	1.2	1.2	11.0
Input end ring	35.0	3.9	41.6	4.6	0.1	0.1	-	0.3	1.0	4.4	0.4	1.6	0.7	5.0
Helix connector	39.4	4.3	47.9	5.3	0.1	0.2	2.0	0.7	1.8	10.4	1.2	3.6	1.3	11.1
Slotted helix barrel	28.1	3.1	32.0	3.5	0.1	0.1	0.6	0.6	1.5	10.1	0.5	2.2	0.6	9.7
End ring	39.3	4.3	45.5	5.0	0.1	0.1	-	1.1	0.6	7.1	0.3	1.0	0.4	6.8

Notes:

1. At 600°C, all parts except the pole piece support showed traces of m/e 32 which is probably O_2.
2. At 1000°C, no m/e 32 was detected in any sample.
3. All samples showed sources of m/e 30, probably NO, and traces of C_2 and C_4, hydrocarbons.

* - 20 minute collection

The 1-4BE tube is composed of 13 kovar parts and 6 internal stainless-steel parts, whereas the 1-3DF tube is composed of three kovar parts and about thirteen stainless-steel parts. From a comparison of the gas content of the kovar and stainless-steel parts in the 1-4BE tube given in the tables referred to above, it is apparent that the kovar evolves more of all the gases measured at 600°C and 1000°C except for H_2 which is greater in the stainless steel. Assuming that the gas content of the stainless-steel parts in the 1-3DF tube are similar in gas content to that of the 1-4BE stainless-steel parts (which is not an unreasonable assumption considering that the kovar parts in both tube types are similar in gas content), the conclusion may be drawn that the total gas ambient of the operating 1-3DF would be lower than that of the operating 1-4BE. The partial pressure of H_2 in the 1-3DF may be higher, however, than in the 1-4BE as there are many more stainless-steel parts in the former tube type. However, small amounts of H_2 may not be deleterious to tube life.[2] This conclusion is only tentative because most of the tube parts analyzed for gas content undergo additional processing when assembled into subassemblies and subsequently into the final traveling wave tube.

3. PROGRAM FOR NEXT QUARTER

1. Complete the life-test and gas-spectra measurements on all tubes in test.
2. Determine the most sensitive electrical test parameters to correlate with the gas ambient of the traveling wave tubes.
3. Continue with omegatron investigation of grids and tungsten spring.
4. Investigate tungsten helices of both tubes with omegatrons.
5. Analyze with the omegatron additional coated heater coils from a new production batch to confirm the experimental evidence presented.
6. Make x-ray diffraction and electron microscope analyses of the alundum coated heater coils from the 1-4BE and 1-3DF tubes.
7. Make further control measurements on an omegatron processed on the ultra-high vacuum system.
8. Correlate all these data.

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2. H. B. Frost, "The Analysis of Residual Gas in Electron Tubes," IRE Transactions on Electron Devices, March 1962.

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